Solid-State Infrared Photosensing

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Taxonomy of Solid-State Photosensing Principles

Semiconductor photosensors

Quantum detectors

- $E_{\text{photon}} > E_{\text{gap}}$
  - Photovoltaic sensing
    - Monolithic SC (Si,Ge,GaAs...)
  - Photocurrent sensing
    - Compound SC (hybrid)
  - Photoconductive sensing
    - oTFA (organic SC on CMOS)
- $E_{\text{photon}} < E_{\text{gap}}$
  - FCA / HIP
  - Inter-sub-band

Thermal detectors

- Pyroelectric
  - Resistive
  - Diode current
- Bolometers
  - Thermo-couples
Contents of the Presentation

Semiconductor photosensors

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Thermal detectors

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- Bolometers
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Monolithic SC (Si,Ge,GaAs...)

Compound SC (hybrid)

oTFA (organic SC on CMOS)

Quantum dots (QD-on-CMOS)

Resistive

Diode current
Compound Semiconductor Photosensors (on CMOS)
Detectivity of Different Types of Infrared Photosensor Materials

In summary, this preliminary work has demonstrated room temperature InAsSb photodetectors operating up to \( \approx 14 \, \mu m \) with performance close to the theoretical limits determined by fundamental limitations. The present InAsSb devices may be already useful for some applications (CO\(_2\) laser monitors, laser warning receivers and others). The monolithic optical immersion should increase the performance to the level comparable to the state-of-art microbolometers, but with much faster speed of response. Further optimization of devices and the use of simple Peltier coolers should bring even improved performance, so that this technology may become a serious challenger to both MCT and microbolometer technologies.

* M. Razeghi, "Longwavelength InAsSb Infrared Photodetectors", ARPA Report, April 1995
Mid-Infrared Quantum Detection: InAsSb

The P12691-201 is an infrared detector that provides high sensitivity, high reliability, and compact, thermoelectrically cooled TO-8 package. The detector is easy to use as it uses a compact package.

**Features**
- High-speed response
- High sensitivity
- High reliability
- Compact, thermoelectrically cooled TO-8 package
- RoHS compliant
- Can be assembled in a module with QCL

**Spectral response (D*)**

(Typ. Td=-30 °C)

![Graph showing spectral response (D*) vs. wavelength (μm)](image)
Quantum Dot Photosensing

- Semiconductor photosensors
  - Quantum detectors
    - $E_{\text{photon}} > E_{\text{gap}}$
      - Photovoltaic sensing
      - Photocurrent sensing
      - Photoconductive sensing
    - $E_{\text{photon}} < E_{\text{gap}}$
      - FCA / HIP
      - Inter-sub-band
  - Thermal detectors
    - Pyroelectric
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- Monolithic SC (Si,Ge,GaAs...)
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- Quantum dots (QD-on-CMOS)
Reminder: Quantum Confinement Photodetection (Electron in a Box)

Potential energy: \( U = 0 \) in the box \((0..L)\), and \( U = \infty \) outside the box

\[
\Psi_n(x) = \sqrt{\frac{2}{L}} \sin \frac{n\pi}{L} x \quad n = 1,2,3,\ldots \\
E_n = \frac{\hbar^2}{8mL^2} n^2
\]
NIR/MIR Cutoff-on-Demand: Quantum-Dots on CMOS Image Sensors

MIR Wavelengths Accessible to Quantum-Dot Photosensing

Free Carrier Absorption – Homojunction Internal Photoemission

Semiconductor photosensors

Quantum detectors

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  - Monolithic SC (Si,Ge,GaAs...)
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- $E_{\text{photon}} < E_{\text{gap}}$
  - Intersub-band
  - Pyroelectric
  - Bolometers
  - Resistive
  - Diode current

Thermal detectors

FCA / HIP
Silicon-Based (CMOS-Compatible) MIR/FIR Photosensing?

IR absorption in doped Si is increasing with the square of the wavelength relationship holds up to wavelengths of several 100 µm (FIR / THz).

Ultra-Wide-Band NIR/MIR/FIR/THz Silicon Photodetection: FCA/HIP

Potential barriers close to the surface, next to highly doped silicon, act as filters for charge carriers excited by the incident IR photons:

Only higher-energy electrons/holes can pass over the barrier, for collection and detection by adjacent electronic circuits.

HIP = Homojunction internal photoemission

Intersubband Infrared Photodetection

- Photovoltaic sensing
  - Monolithic SC (Si,Ge,GaAs...)

- Photocurrent sensing
  - Compound SC (hybrid)
  - oTFA (organic SC on CMOS)

- Photoconductive sensing
  - Quantum dots (QD-on-CMOS)

- FCA / HIP

- E_{\text{photon}} > E_{\text{gap}}
  - Inter-sub-band

- E_{\text{photon}} < E_{\text{gap}}
  - Pyroelectric
  - Bolometers
  - Thermocouples

- Resistive
- Diode current

- Semiconductor photosensors
  - Quantum detectors
  - Thermal detectors
Infrared Photodetection With A Silicon Gate (MOS) Structure

(12) United States Patent
Anthony et al.

(10) Patent No.: US 6,420,707 B1
(45) Date of Patent: Jul. 16, 2002

(54) INFRA-RED DETECTOR

(75) Inventors: Carl J. Anthony; Kevin M. Brunson; Charles T. Elliott; Neil T. Gordon; Timothy J. Phillips, Michael J. Uren, all of Malvern (GB)

(73) Assignee: QinetiQ Limited, London (GB)

( * ) Notice: Subject to any disclaimer, the term of patent is extended or adjusted under U.S.C. 154(b) by 0 days.

(21) Appl. No.: 09/297,176
(22) PCT Filed: Nov. 6, 1997
(86) PCT No.: PCT/GB97/03053
§ 371 (c)(1), (2), (4) Date: Jul. 21, 1999
(87) PCT Pub. No.: WO98/21757
PCT Pub. Date: May 22, 1998

OTHER PUBLICATIONS


Potential Distribution In A (Silicon) MOS Structure

- Charge confinement - Quantized energy levels!

- Fully depleted (10V)
- Potential well 1/3 full
- Thermal equilibrium
Silicon-Based Inter-Subband Voltage-Tuneable Infrared Detectors

Energies of the lowest four electric subbands for a 001 silicon surface whose p-type substrate contains $4.5 \times 10^{14}$ acceptors/em$^3$ uniformly distributed. The ellipsoidal nature of the electron conduction bands implies two possible $m_2$ values leading to two discrete electric band ladders. Since transitions between states derived from different mass are forbidden in the dipole approximation, the diagram does not show the light mass ladder.

Silicon-Based Inter-Subband Voltage-Tuneable Infrared Detectors

C.J. Anthony et al. (Qinetiq), ”Infra-Red Detector”, US Patent No. 6,420,707 B1, 2002
Inter-Subband Voltage-Tuneable Silicon Infrared Detectors

Potential slope $dV/dz$ (max. electric field) at silicon/oxide interface:

$$E_{max} = \sqrt{\frac{2q}{\varepsilon_0 \varepsilon_{Si}}} N_S V_G$$

$V_G$: Gate voltage

$N_S$: Substrate doping

Device design and Si technology!
Affordable Solid-State Infrared Photodetection and Image Sensing

The overall goal is to conquer the EIR [Extended Infrared Spectral Range] with a complete toolbox of low-cost active and passive photonic devices [100x cheaper] …
Thank you very much!

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